Coagulation in Dusty Plasmas. L. S. Matthews and T. W. Hyde, *Space Physics Theory Group, Department of Physics, Baylor University, Waco, TX 76798-7316, USA*

Introduction

Dusty plasmas are an ubiquitous component of space, found in protostellar clouds, protoplanetary disks, cometary tails, and in the planetary rings. As a result, the physics underlying the manner in which microscopic dust grains interact with one another and their plasma/gas environment is a field of research having broad implications on our understanding of the development of astrophysical systems.

This paper will examine a numerical model for coagulation based on the Box_Tree code. Preliminary results are given showing coagulation of dust grains with no self-interactions, grains interacting through self-gravity only, and charged grains interacting gravitationally and electrostatically.

Coagulation and Planetary Formation

Most planetary formation theories currently assume that the process begins with the gravitational accretion of planetesimals formed in the primitive solar nebula from microscopic grains. It is presently believed that planetesimals form from an original population of 1 to 10 km-sized objects, themselves formed via the coagulation of smaller objects constructed from the constituents of the protoplanetary disk, namely gas and micron sized dust particles. This coagulation process depends on unknown and poorly defined properties of the nebula and of the dust particles themselves and as a result is not yet well understood.

Until recently, the majority of planetary system formation models predicted the development of "planetary embryos" from the runaway growth of planetesimals. These embryos were thought to increase in size with heliocentric distance. Special emphasis was placed on recreating our own solar system: gas giants forming beyond the ice zone and smaller rocky planets forming in closer to the star. As a result, it was assumed that a Jupiter type planet must form early on in order for the inner rocky planet formation to then occur. However, recent experimental evidence has shown that extremely large planets can indeed form much closer to the protostar than expected, setting current theories on their ear[1]. Thus an understanding of the dynamics of planetesimal formation via the coagulation of small dust grains is even more crucial to the understanding of planetary system formation. It is now clear any successful theory must initially answer the coagulation question.

Numerical Model

As mentioned above, the nebular dust particles are imbedded in a plasma and thus become charged. The resulting dust dynamics are affected not only by self gravitation between the particles as well as gas drag, but also by the electromagnetic interactions between the charged grains. The grains tend to become negatively charged since the electrons in the plasma have a much greater velocity than do the ions and therefore will collide more frequently with the dust grains than ions with the same thermal energy. This has the effect of inhibiting coagulation, especially for micron sized grains where the electrostatic force can be orders of magnitude larger than the gravitational force. It appears, however, that this may be partially offset by secondary electron emission which can lead to oppositely charged grains for a dust cloud with a range of grain sizes, greatly enhancing coagulation[2].

To accurately model the coagulation of micron sized dust grains in a protoplanetary environment, it is necessary to keep track of a large number of particles while noting collisions that result in sticking. In the current study, this was accomplished using a numerical model based on the Box_Tree code[3]. The Box_Tree code models a ring or disk by first dividing it into self-similar patches orbiting the planet or star, where the box size is much greater than the radial mean excursions of the constituent dust grains. Boundary conditions are met using ghost boxes, eight for 2-D simulations and twenty-six for 3-D simulations. A tree code is incorporated into the Box_Tree routine to allow it to deal with gravitational interactions between the particles. Using this code, a full treatment of rigid body dynamics, including rotation, is possible allowing for both cluster trajectories and the orientation of fractal aggregates to be followed. Since the dust cloud in a plasma is charged to a non-zero potential, a tree code lends itself to the calculation of the electrostatic forces between the particles as well.

Results

Initial base line tests were run on a collection of particles ranging in size from 1 to 6 microns. In Figure 1, the results are shown for coagulation with no electrostatic or self-gravitational interactions. Figure 2 displays the coagulation with self-gravitation only, while Figures 3 and 4 show coagulation for grains charged to the same potential and opposite potentials, respectively.

Further tests of the coagulation model are necessary incorporating realistic parameters while differing astrophysical environments. Additionally, such effects as Debye shielding and the dynamic charging of the dust grains need to be included in the code. The coagulation of dust grains must occur for planetary formation to take place; if electrostatic effects are shown to halt or greatly inhibit coagulation, our present understanding of this process as well as our current understanding of protoplanetary formation must be re-examined and new theories brought forward.

References

(1) Boss, Alan P., Proximity of Jupiter-Like Planets to Low- Mass Stars, *Science*, **267**, 360-362, 1995.

(2) Chow, V. W., D. A. Mendis, and M. Rosenburg, Role of Grain Size and Particle Velocity Distribution in Secondary Electron Emission in Space Plasmas, *Journal of Geophysical Research*, **98**(A11), 19,065-19,076, 1993.

(3) Richardson,. Derek C., A Self-Consistent Numerical Treatment of Fractal Aggregate Dynamics, *Icarus*, **115**,320-335, 1995.

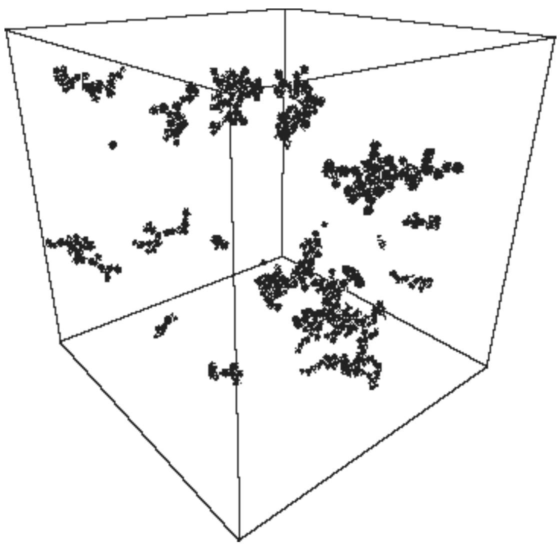

Figure 1. Coagulation with no electrostatic or self-gravitational forces.

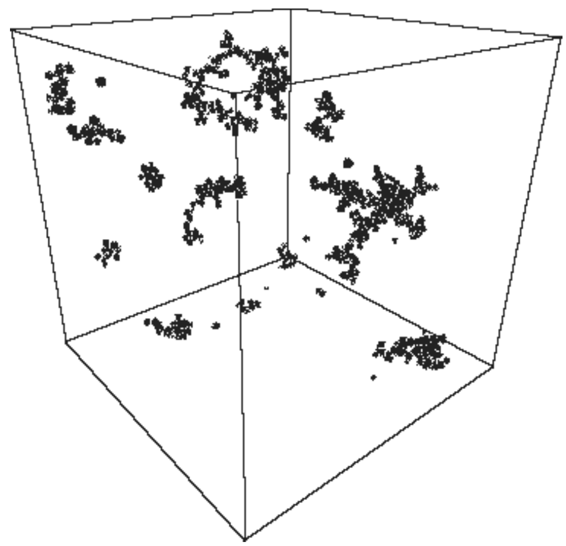

Figure 2. Coagulation with self-gravitation.

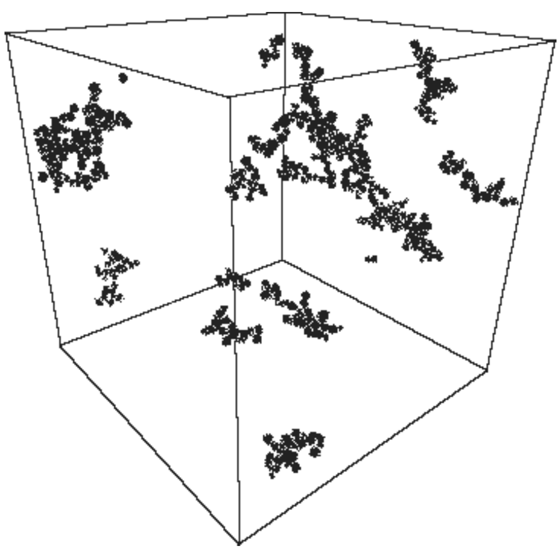

Figure 3. Coagulation with self-gravitation and electrostatic forces: all grains charged to ~-1V.

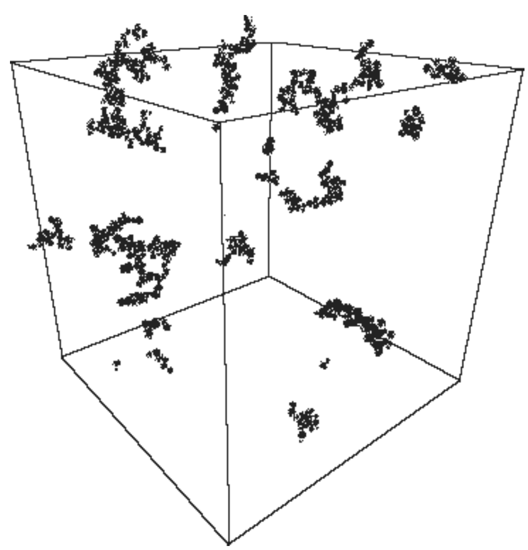

Figure 4. Coagulation with self-gravitation and electrostatic forces: larger grains are charged to a potential of ~4V, grains smaller than 3μ to ~-1V.

In Figures 1-4, each simulation was run for 3500 seconds with 700 particles ranging in size from 1 to 6 μ. The box size is 450μ to a side.